Automated Control of Pasteurization in Wine Production

Vladimir Hristov
Department of Electrical Motion Automation Systems, Faculty of Automatics
Technical University of Sofia
Sofia, Bulgaria
vdhristov@tu-sofia.bg

Danail Slavov
Department of Electrical Motion Automation Systems, Faculty of Automatics
Technical University of Sofia
Sofia, Bulgaria
d.slavov@tu-sofia.bg

***Abstract*—This paper presents an installation for the process of wine pasteurization as automation object with the corresponding controllable dimensions, control and inference impacts. Designed automated control system is described with three operation modes: loading, washing/preheating and product processing. Detailed algorithm illustration and description is included. The system is implemented using Siemens S7-1200 PLC controller. Finally, research work is conducted for determination of the regulator coefficients needed to maintain the proper state of wine pasteurization.**

Keywords— Siemens controller, wine pasteurization, process automation, control system, Ladder, PID control

I. INTRODUCTION

Pasteurization is a process of high-temperature heating of products which aims to destroy bacteria, viruses, other unicellular organisms, molds and yeasts. It is named after its discoverer, Louis Pasteur (1822 – 1895).

There are several types of pasteurization, depending on the temperature range, duration and use of high pressure. The original method was vat pasteurization, which heats the product in a large tank to around 60 ºC for at least 30 minutes. It is now used primarily in the dairy, wine and beer industry. The most common method of pasteurization is High Temperature Short Time (HTST) pasteurization, where product is heated to 71.5 – 74 ºC for not less than 15 seconds, followed by rapid cooling. It is used in preservation of fruit juice where higher than this temperatures are undesirable. Higher Heat Shorter Time (HHST) is a process similar to HTST, but it uses slightly different equipment and higher temperatures (90 – 100 ºC) for a shorter time (0.01 – 1.0 seconds). In Ultra Pasteurization (UP), the product is heated to not less than 138 ºC for two seconds. UP pasteurization results in a product with longer shelf life but still requiring refrigeration. High Pressure Processing (HPP) is a cold pasteurization technique by which products, already sealed in its final package, are introduced into a vessel and subjected to a high level of isostatic pressure (300 – 600 MPa / 43,500 – 87,000 psi) transmitted by water.

II. PASTEURIZATION IN WINE INDUSTRY

Wine pasteurization is done by heat processing with temperatures up to 100 °C, which destroys all vegetative forms of microorganisms found in the wine, without substantial changes in its composition and properties. Pasteurization should be regarded as a means of decontamination and shelf life extension, not as product quality improvement. The effect of pasteurization depends on its duration and temperature level [1].

There is a large variety of pasteurizers. Most often, low-temperature pasteurization is carried out in vats with periodic operation. The wine is placed in a vat with a sheath through which warm water circulates, and the heat exchange is facilitated by an equipped agitator. More advantages offer continuous operation pasteurizers – pipe-flow or laminar-flow heat exchangers. The latter (Fig. 1) have the best thermo-technical characteristics and they can be utilized for flash pasteurization, a type of HTST [1].

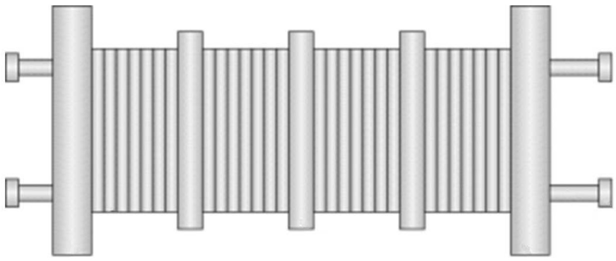

Fig. 1. Laminar-flow heat exchanger

The heat carrier is steam or hot water, and the cold carrier is cold or iced water. Fig. 2 shows a schematic diagram of laminar exchanger for wine.

Through pump 1, raw wine enters into the regenerative heat exchange section 2. Here, using the heat of the already pasteurized wine (which moves in a counterflow on the other side of the laminae), cold wine heats up to a temperature of 35 ÷ 50 °C. From the regenerative section, warmed-up wine passes into the pasteurizing section 3 where, by the effect of the heat carrier, reaches a pasteurization temperature, after which enters into the containment vessel 4. From there, through pump 5, pasteurized wine goes to the regenerative section one more time, where transfers some of its heat to the raw wine entering for pasteurization. After that, it goes into the cooling section 6, where its temperature drops to 35 °C. In a flash, high-temperature pasteurization, both vessel 4 and pump 5 are not needed.

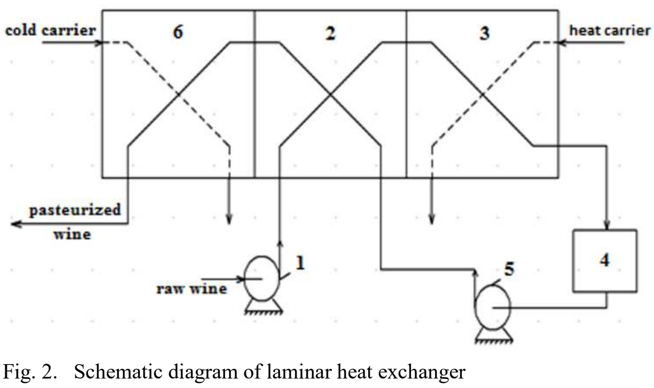

Fig. 2. Schematic diagram of laminar heat exchanger

978-1-6654-4058-5/21/$31.00 ©2021 IEEE

Modern wine pasteurization installations can be regarded as automation objects with the following input/output dimensions [1]:

- Main controllable dimensions: pasteurization temperature, cooling temperature
- Intermediate controllable dimensions: temperature after the interaction with the heat carrier, wine level in the buffer vessel, temperature of pasteurized wine at the installation output
- Control impacts: heat-carrier (or wine) flow rate, cold-carrier flow rate, speed of the pump after the buffer vessel
- Interference impacts: wine initial temperature, changes in characteristics of heat and cold carriers, wine flow rate (if the heat-carrier flow rate is a control impact) or heat-carrier flow rate (otherwise)

Specific interference for pasteurizers is deposition of wine precipitates on the inner surfaces, which over time leads to significant aggravation of heat exchange. This requires regular installation flushing.

Heat balance of the laminar heat exchanger is expressed by the equation [1]:

$$(1-e)F_W c_W(\theta_{PW}-\theta_{IW}) = F_S(i - c_{SC}\theta_{SC}) \qquad (1)$$

where F_W and F_S – flow rates of wine and steam; c_W and c_{SC} – specific heat capacities of wine and steam condensate; θ_{PW} , θ_{IW} and θ_{SC} – pasteurized wine temperature, initial wine temperature and condensed steam temperature; *i* – specific steam enthalpy; *e* – coefficient of heat regeneration in the regenerative section of the pasteurizer.

III. Design and Description of Automated Control System for Wine Pasteurization Unit

The pasteurization system is illustrated in Fig. 3 and the control algorithm is in Fig. 4.

At system start-up, the level of secondary heat carrier in CV 1 is checked. If it is below minimum (lower) level, carrier loading starts, while at the same time its heating-up is forbidden. During this loading, only the pneumatic two-way valves FV 112 and FV 113, level sensor LIC 112, and secondary carrier pump P 111 have operation permissions. Initially, when the buffer vessel CV 1 is empty, operation of pump P 111 is forbidden. When the FV 112 and FV 113 valves open, the secondary heat carrier system starts to load. When the maximum (upper) level is reached (measured by LIC 112), valve FV 113 closes, as well as valve FV 112 (which closure is forbidden while FV 113 is open). At the two valves closure, the pump P 111 receives a start-up permission. It works for 5 minutes, during which time the rest of the secondary carrier system is loading (until now, only the buffer vessel CV 1 has been filled up) and the volume of warm water in CV 1 decreases. If minimum level is reached before the 5-minute time lapses, the pump P 111 stops its operation, the two valves FV 112 and FV 113 open, and the buffer vessel starts filling again until the maximum level is reached. This routine repeats until the max level has been reach without the pump having to stop its 5-minute operation, which means the loading is complete. Until then, operation mode is forbidden.

In operation mode, the P 102 product pump is disabled, until the fixed-level vessel VCL has been filled up. This is to avoid running the pump dry. In this mode, FV 112 and FV 113 valves' operation is forbidden. Only the LIC 112 sensor is enabled which measures the CV1 vessel's level and if the min level is reached, the sensor closes the TCV 104 valve of the steam system and stops both pumps P 102 and P 111. The pump for feeding the fixed-level vessel with product is started manually. In most cases, it should be started before the HV 101 valve is opened, in order to avoid delay in the vessel filling.

Reaching max level starts the product pump P 102 and reaching min level stops it. The pump is controlled by the frequency regulator FIC 102 using a flowmeter. The flow rate is set by the operator.

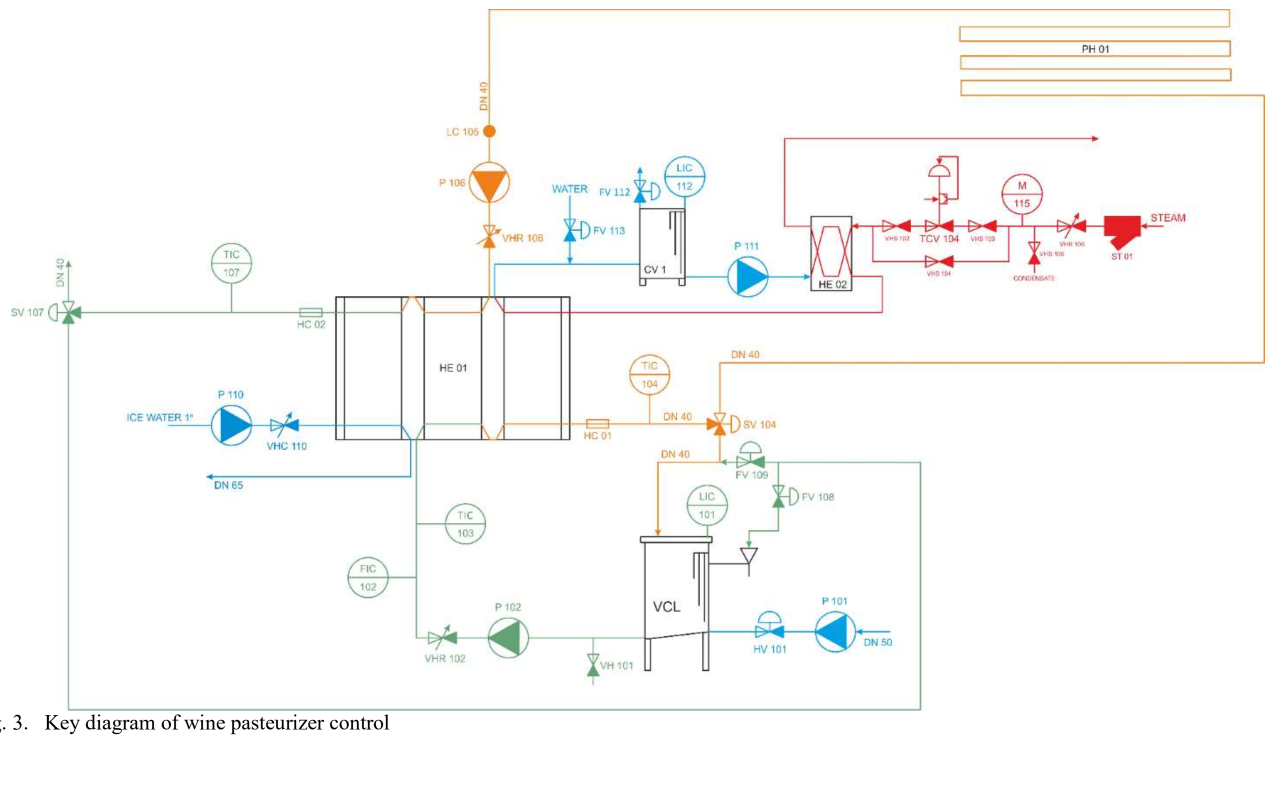

Fig. 3. Key diagram of wine pasteurizer control

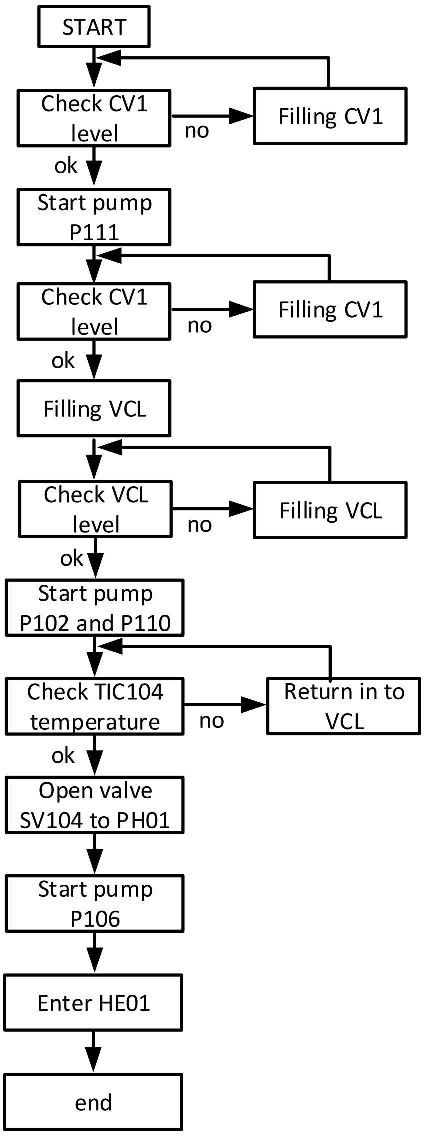

Fig. 4. Pasteurizer system control algorithm

TIC 103 shows the product temperature at pasteurizer entrance, while TIC 104 reads the temperature at the exit of the pasteurization section (i.e. wine pasteurization temperature) and maintains it by means of control over the automatic pneumatic diaphragm valve TCV 104. Wine heating temperature is set by the operator. When the secondary heat carrier begins to heat up, TCV 104 receives enabling signal for opening. If the P 111 pump is not operating, TCV 104 closes. TIC 104 also controls the pneumatic three-way valve SV 104: it opens the valve to the VCL vessel, if the set value for pasteurization temperature is not reached, or otherwise – to the tubular restraint PH 01, where the product remains for 30 seconds. At the pasteurization section exit, there is a manhole HC 01, where the product onflow can be monitored. This enables manual change of the FV 104 position.

After PH 01, there is a product pump P 106 located. It is protected against dry running by the level sensor LC 105 and is enabled at the moment of SV 104 opening to the tubular restraint. Through this pump, wine enters into the regenerative section of the heat exchanger, transfers some of its heat to the raw wine, and then enters into the cooling section where its temperature drops to 20 °C.

The TIC 107 sensor monitors the product temperature at the heat exchanger exit. The three-way valve SV 107 is controlled by a level sensor located in the filling machine. The valve opens to the VCL vessel (recirculation mode) if max level is reached, and to the filling machine if min level is reached. This can also be controlled manually depending on the wine onflow, seen through the manhole HC 02 at the cooling section exit.

In automatic operation mode, FV 109 is fixed open and FV 108 is fixed closed. In this mode, the operator can only control the opening and closing of the two valves. While FV 108 is open, the opening of FV 109 is forbidden.

IV. Wine Pasteurizer Implementation

Process automation is implemented with a Siemens series S7-1200 PLC controller. Compact design, low price and large instruction set make the S7-1200 an appropriate solution for control of many applications. [2]

The software program through which the system is controlled, is written using SIEMENS TIA (Totally Integrated Automation) Portal and the Ladder Diagram programming language (relay logic circuit). It allows development of different control algorithms, for example ones for optimal tool position searching of magazine drives [3] which can take into account the type and the number of tools, the respective transfer mechanism, and the sensors used. Applications programmed with this language can be of particular importance for the proper system operation, decreasing energy consumption and prolonging the equipment service life. [4] The implemented system allows for setting different values for the target pasteurization temperature, as well as automatic and manual operation modes.

During the pasteurizing system operation, a human-machine interface (SIEMENS HMI Comfort Panels, Fig. 5) is also used.

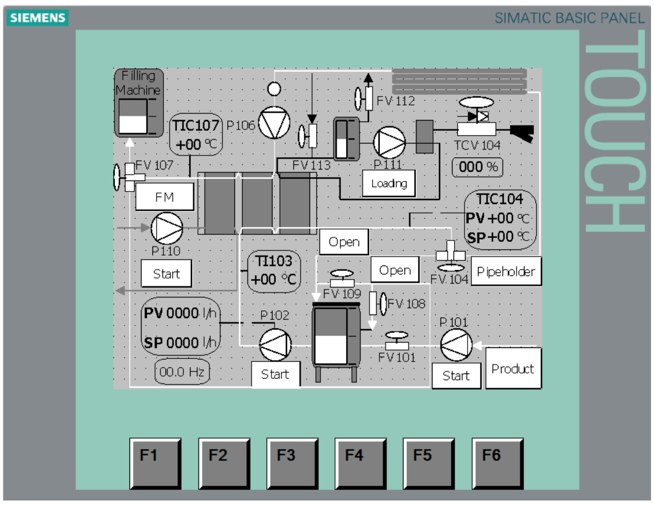

Fig. 5. HMI main screen

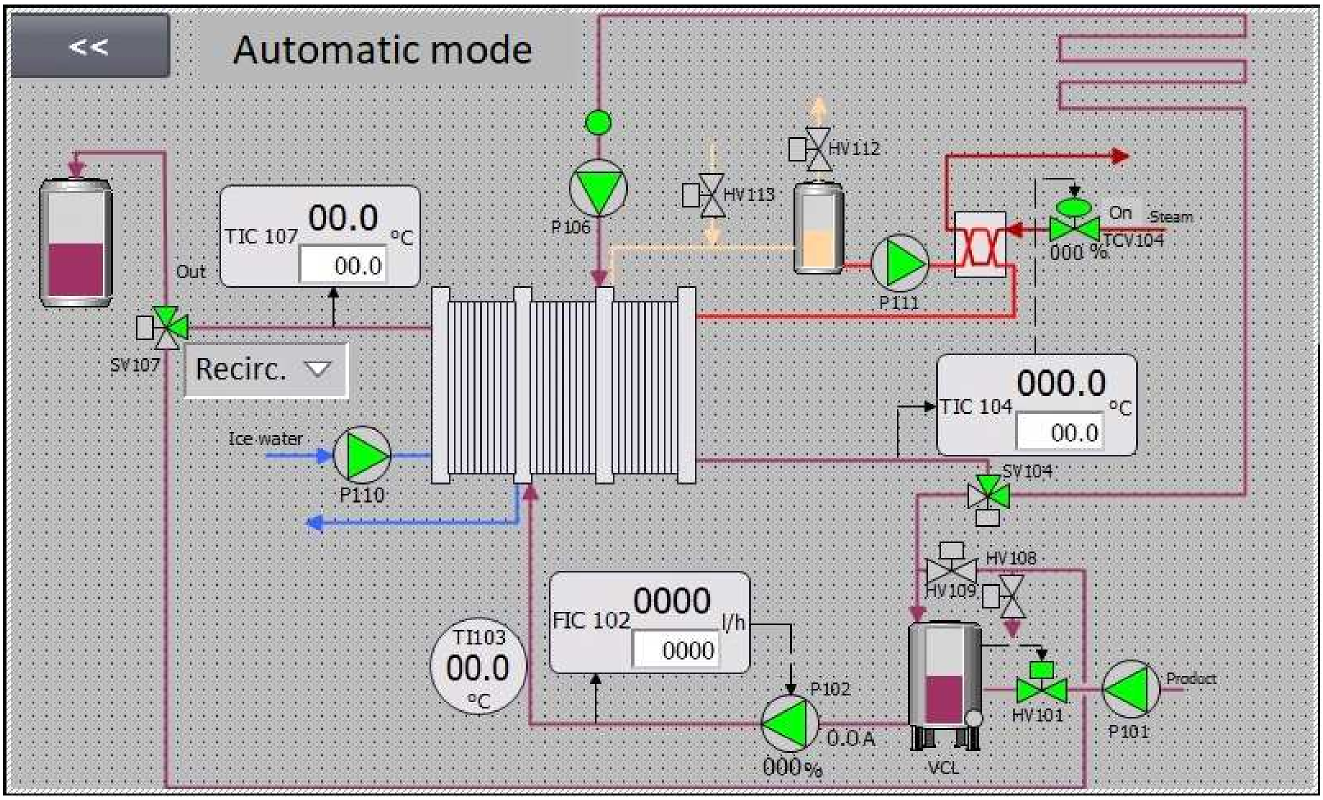

Fig. 6. Pasteurizer during operation in the Siemens Simatic HMI

Technical specifications of the wine pasteurizer are:

- throughput 2,000 l/h
- input wine temperature 20 °C
- wine heat-up temperature 65 ÷ 70 °C
- output wine temperature 20 °C
- primary heat carrier steam (3.5 bar)
- secondary heat carrier hot water
- cold carrier ice water (1 °C)

The pasteurizer start-up begins with water filling of the intermediate heat carrier system, as described above. When it is accordingly flooded, an operation permission is issued. The next stage is washing/preheating. Water filling of the fixed-level vessel VCL is initiated: the HV 101 valve opens and the P 101 pump starts. When the high level of the buffer vessel is reached, HV 101 closes and P 101 stops. The P 102 and P 111 pumps turn on as soon as the VCL low level is reached. If, at any occasion, the liquid (water or wine) falls below the low level, P 102 stops, as this is an emergency instance.

With the initiation of P 102, the installation preheating begins: the SV 104 valve is in recirculation mode (towards VCL), and the TCV 104 valve begins adjusting the steam flow so that the TIC 104 readings attain the target temperature. When it is reached, SV 104 opens towards the tubular restraint and the P 106 pump begins operation.

System stabilization is to be performed before feeding it with product. During this stage, both pasteurization and output temperatures are monitored. After reaching the target values, a wait time of one minute is applied for their stabilization. At this point, the operator must have already ensured the product path before and after the installation. Before the wine is fed, the water level in VCL should reach the minimum, in order to avoid mixing a large amount of product with water. Then, the pasteurizer operation continues as described in Section III. Fig. 6 shows a Siemens HMI panel of the system during operation.

When the whole amount of product is pasteurized and before the installation is stopped, it has to be washed again. For this purpose, the operator should ensure clean water inflow.

After the product in the buffer vessel reaches low level, the water is fed to the system and it starts pushing the wine towards the exit. When the water reaches the HC 02 manhole, the operator switches SV 107 in recirculation mode, opens the VH 101 manual valve towards a drain and closes the TCV 104 valve. With this, the steam inflow stops and system cooling is performed until temperature readings from both TIC 104 and TIC 107 reach below 40 ºC.

V. Research

On Fig. 7 is a diagram of the input flow-rate regulator. Notations used are: PV – measured value of the input flow rate; SP – set value of the input flow rate, which is the regulator target. For the frequency control FT 102 of the P 102 pump, PI controller action is used.

Fig. 7. PI regulator controlling the input flow-rate

The next diagrams show the results of the research conducted in tuning the regulator for pasteurization temperature control TIC 01 (TIC 104). Initial research used PI controller action (Fig. 8).

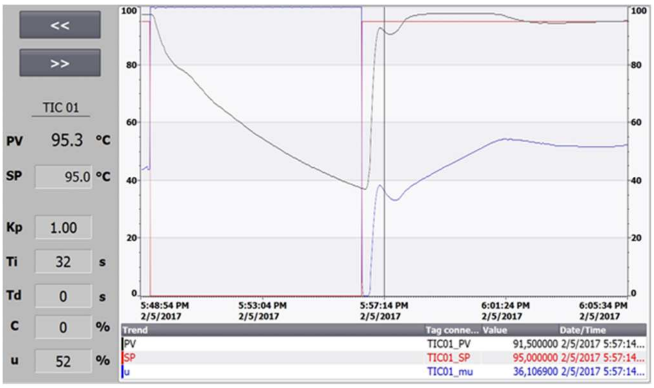

Fig. 8. Controlling the pasteurization temperature with a PI controller. PV – measured value; SP – set (target) value; u – control impact of the regulator (%).

Subsequently, it become clear that the regulator is acting too slow and would not manage to smoothly sustain the set pasteurization temperature in case of small variations of the input steam pressure. This would lead to high peaks and persistent fluctuations. Therefore, the next test uses a larger proportional component $Kp = 3$, integral component $Ti = 60$ and an additional differential component $Td = 3$, which comprises a PID controller action (Fig. 9).

VI. Conclusions

Implementation and research activities described herein lead to the conclusion that the wine pasteurization aggregate allows the utilization of two of the most common pasteurization technologies:

- High pasteurization – heating to a temperature of 95 °C with a holding time up to 1 min, followed by cooling;
- Instant (continuous) pasteurization – heating to a temperature of 100 °C with a duration of several seconds, followed by product cooling.

With the help of the automated program for control of the wine pasteurization aggregate, the work of the operator is facilitated, and the human error is reduced in performing the pasteurization process. The research conducted shows the operational capability of the system and allows for determination of the regulator coefficients which are needed to maintain the temperature of wine pasteurization.

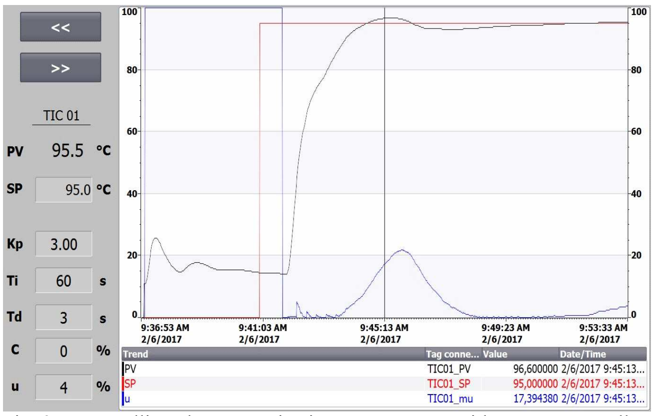

Fig. 9. Controlling the pasteurization temperature with a PID controller. PV – measured value; SP – set (target) value; u – control impact of the regulator (%)

Described system is open for further improvement and expansion with new functions which would be helpful for its users. Monitoring, detection and prompting options for system washing can be added which would ensure that the operator washes the pasteurizer before and after its use. This is very important for the proper operation since debris bedding over time deteriorates heat exchange as well as controller performance and can prevent the achievement of results inherent to a clean system.

Acknowledgment

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

This paper is a part of author's participation in the National Program "Young Scientists and Postdocs".

References

[1] К. Наплатаров и М. Рабаджийски, Промишлени технологии и инсталации, София: ТУ - София, 1999.

[2] Siemens, "Siemens Simatic S7-1200 Programmable Controller System Manual," Nürnberg, 2012.

[3] M. Mikhov and M. Zhilevski, "Control Device for Tool Magazine Drives of Vertical Machining Centers with CNC," in *2020 International Congress on Human-Computer Interac-tion, Optimization and Robotic Applications (HORA)*, Ankara, 2020.

[4] M. Zhilevski and M. Mikhov, "Control Device for a Type of Machine Tools," in *2020 International Conference Automatics and Informatics (ICAI)*, Varna, 2021.